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Carbon footprint trends of metropolitan residents in Finland: How strong mitigation policies affect different urban zones

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ABSTRACT

Around the world, cities are creating local climate change mitigation strategies and combining strengths in international efforts. In addition to making the strategies, it is important to follow, how they work in practice. The aim of the study is to examine, how climate change mitigation policies and other events affected the consumption-based household carbon footprints in the Helsinki Metropolitan Area (HMA) from 2006 until 2012. The cities of the HMA launched an ambitious climate change mitigation strategy in 2007. Furthermore, the study analyses the changes in the carbon footprints of six different types of urban zone within the HMA: the central pedestrian zone, the fringe of the central pedestrian zone, intensive public transport zone, public transport zone, car zone and the pedestrian zones of subcentres. The results of the study reveal that the average carbon footprint decreased 7% from 2006 to 2012, despite 1% increase in expenditure, which is encouraging. Emissions caused by housing energy consumption and motor fuel consumption decreased the most. Among the urban zones, public transport zone and car zone, which are the two outermost zones of the HMA, had the strongest emission reductions. Cleaner electricity and the improved energy efficiency of buildings had a strong effect. The regression analysis of the study suggests that the central pedestrian zone and the car zone, the two most affluent zones of the HMA, have higher carbon footprints than all the other zones have between them. However, this is only true when income is controlled, not when expenditure is controlled. The economic crisis in 2008, and changes in consumption behaviour because of it, seem to explain the result. The reduction of the average carbon footprint in the HMA was not only due to steered mitigation actions. Increased housing costs seem to have contributed to the decline of consumption-based emissions. The results of the study suggest that to achieve the ambitious international, national and local climate change mitigation targets, stronger measures are needed.

1. Introduction

Several studies have found that the global urbanization tends to increase energy consumption and greenhouse gas (GHG) emissions (York et al., 2003; Lenzen et al., 2008; Rosa and Dietz, 2012; Zhang and Lin, 2012; Ponce de Leon Barido and Marshall, 2014; Wiedenhofer et al., 2017). It has been suggested that urbanization is not only a consequence but also a driver of economic growth (Cervero, 2001; Glaeser and Gottlieb, 2009). Growing cities attract and create investments and increase the income and consumption of their citizens. Consumption-based emissions per capita generally increase with the level of urbanity when rural areas and small towns are compared to large cities and metropolitan areas (Lenzen, 1998; Brand and Preston, 2010; Heinonen et al., 2013a; see also Seto et al., 2014). As it has already been claimed that cities are responsible for up to 70–80% of the global GHG emissions (Hoornweg et al., 2011; Seto et al., 2014), the pressure on cities to mitigate climate change is increasing, and the question of decoupling economic growth and environmental burdens is topical.

Around the world, cities have responded by creating local climate change mitigation strategies and combining strengths in international efforts, such as the C40 Cities Climate Leadership Group (www.c40.org), the Global Covenant of Mayors for Climate and Energy (www.globalcovenantofmayors.org) and ICLEI ("Local Governments for Sustainability") (www.iclei.org/). Finland, as an

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affluent country, belongs to the top end in global carbon footprint comparisons (Hertwich and Peters, 2009; Davis and Caldeira, 2010; Ivanova et al., 2016). The capital region, the Helsinki Metropolitan Area (HMA), has been found to have the highest carbon footprints in the country (Heinonen et al., 2013a; Ala-Mantila et al., 2014) but is also one of the leaders in setting climate targets and imposing mitigation policies. The HMA presented a climate change mitigation strategy in 2007 (YTV, 2007) and revised it in 2012 (HSY, 2012). The strategy includes a variety of climate change mitigation measures targeting the direct GHG emissions caused by energy production and consumption, transportation and waste. Some central mitigation measures highlighted in the strategy are the energy efficiency of buildings and vehicles, renewable energy production, decreasing car use by increasing public transportation use and enhancing cycling and walking, avoiding urban sprawl by concentrating new construction to areas that are connected to existing railway and district heat infrastructures, and education and providing information. In 2007, the cities of the HMA set a target to decrease the GHG emissions by 39% by 2030 compared to the 1990 level. In the 2012 revision, they declared an aim to achieve carbon neutrality in 2050.

Just as important as making climate change mitigation strategies is following how they work. The aim of the study is to examine how climate change mitigation policies and other events affected the consumption-based carbon footprints in the HMA from the starting point of 2006 until the year 2012. The consumption-based GHG assessment allocates the life cycle emissions of goods and services to consumers and has the benefit of capturing the rebound effects of consumption (Ottelin, 2016). Thus the study reveals whether the climate change mitigation strategy has reduced the overall carbon footprints or led to shifts from direct GHG emissions from the city to indirect emissions from consumption. The chosen period is also interesting because it shows the influence of the economic crisis in 2008.

At a more detailed level, the study examines the impact of climate change mitigation strategies in different urban zones. Compact city policies have become generally accepted guidelines for cities to decrease GHG emissions, as is also evident in the HMA's mitigation strategy. Transport accounts for 14% of global GHG emissions (IPCC, 2014) and 23% of total GHG emissions in the EU (Eurostat, 2017). Road transport alone causes approximately 19% of GHG emissions in the EU. Studies on travel behaviour have demonstrated that high-density, mixed-use neighbourhoods and transit-oriented development decrease driving (see reviews by Badoe and Miller, 2000; Crane, 2000; Cao et al., 2009; Ewing and Cervero, 2010; Næss, 2012) and thus lead to lower emissions being caused by car use. Several studies have also demonstrated how suburbanization undermines the possible GHG benefits of urban population density, at least in the US (Glaeser & Kahn, 2010; Jones and Kammen, 2014).

However, recently many consumption-based studies have concluded that the impact of urban structure on energy requirements and the carbon footprints of households may be small after all, while income and household size are the main determinants (Lenzen et al., 2004; Baiocchi et al., 2010; Heinonen et al., 2013b; Minx et al., 2013; Wiedenhofer et al., 2013; Ottelin et al., 2015; Ala-Mantila et al., 2016). What transport and travel behaviour studies alone do not show is that the decrease of driving is reflected in other consumption behaviour (Ottelin, 2016). Furthermore, the changes in urban structure may affect consumption beyond travel behaviour (Heinonen et al., 2013a; Ottelin et al., 2015; Ala-Mantila et al., 2016). Several previous studies have also highlighted the differences in energy requirements and GHG impacts due to different lifestyles in various urban structures (Lenzen et al., 2008; Baiocchi et al., 2010; Heinonen et al., 2013a, 2013b; Wiedenhofer et al., 2013). In general, the results emphasize the importance of having a broad scope when assessing the impact of urban structure on GHG emissions.

The study continues the long line of consumption-based GHG assessments. By studying one specific metropolitan area and detailed urban zones, we overcome some problems that previous carbon footprint studies in the built environment have raised (Minx et al., 2013; Jones and Kammen, 2014): the lumping together of different urban areas and the crudeness of urban structure measures. The study includes six types of urban zones: the central pedestrian zone, the fringe of the central pedestrian zone, intensive public transport zone, public transport zone, car zone and the pedestrian zones of subcentres. The urban zones have been defined by the Finnish Environment Institute (FEI). The key features that distinguish the zones are the distance from the city centre, the frequency of public transportation and distance to the closest station or stop, the population and workplace density, and the level of services in the area. The time dimension of the study also gives important new insights that fully cross-sectional studies alone cannot achieve. We use Statistics Finland's Household Budget Surveys of 2006 and 2012, and the Finnish input-output (IO) model, ENVIMAT (Seppälä et al., 2011), to calculate the carbon footprints. In addition, we use regression analysis to control the impact of income, expenditure, household size and age in order to examine the impact of the urban zone on carbon footprint.

In the next section, we present the research material and methods. After that, we provide an analysis of the economic and demographic development of the HMA in order to give background information on relevant changes in the studied area and urban zones during the study period. Then we present the combined results and discussion, starting with the average carbon footprints and continuing to the results of regression analysis. In the same section, we also present the limitations of the study and policy implications. We end the paper with conclusions.

2. Material and methods

2.1. Research material

The main research materials of the study are the Statistics Finland's Household Budget Surveys of 2006 and 2012 (Statistics Finland, 2006,2012). The surveys consist of detailed data on households' consumption in Finland. The expenditure data is arranged based on the international COICOP (Classification of Individual Consumption by Purpose) division. The survey includes socioeconomic information and some details on housing, such as building type and the year of construction. The surveys cover all of Finland with a stratified cluster sampling design and total sample sizes of about 4000 and 3500 households respectively. Of these households, 568 in 2006 and 629 in 2012 lived in the HMA, and these are the sample sizes of the study. The HMA includes the cities of Helsinki, Espoo and Vantaa. The surveys include probability weight coefficients to correct biases in the demographics of the sample. These biases are due to the variation in response rate between different segments of population. We employed these coefficients throughout the study.

For the purpose of the study, we added the travel-related urban zones defined by the FEI into the data sets (Ristimäki et al., 2013; FEI, 2017a). Fig. 1 presents these urban zones in the HMA. The urban zones are based on the theory of urban fabrics, which recognizes walking city areas, transit city areas and automobile city areas (Newman et al., 2016). The fabrics are actually overlapping in practise, but the zones used in the study are mutually exclusive. The FEI defined the zones by dividing urban regions into zones based on

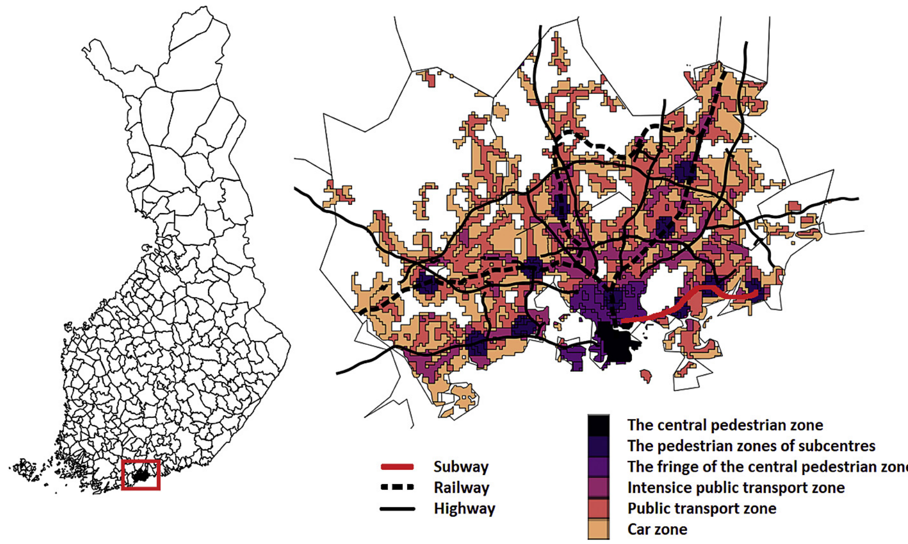

Fig. 1. The studied urban zones in the Helsinki Metropolitan Area (data sources: FEI, 2017b; National Land Survey of Finland; Finnish Transport Agency).

their location and public transportation supply. The main data sources were travel surveys and GIS-based land use information. The key parameters defining the urban zones are the distance from the city centre, the frequency of public transportation and distance to the closest station or stop, the population and work place density, and the level of services in the area. The GIS data on the urban zones is freely available (FEI, 2017b). In the study, we attached the data into the household budget surveys to find the residential location of the households in these zones.

The urban zone data used in the study is from the year 2010, and we used it for both 2006 and 2012 data sets. Thus, there may actually be some minor changes in public transportation accessibility and population density etcetera within the zones. This does not undermine the results of the study but affects how one should interpret the results. The study does not depict how urban zones have widened or shrunk but simply how things have changed within rigid geographical areas, that is to say, urban zones in 2010.

2.2. EE IO analysis and hybrid life cycle assessment

We assessed the carbon footprints of the residents of the HMA with a hybrid life cycle assessment (LCA) based on environmentally extended input-output (EE IO) analysis. EE IO analysis is an established method used to assess the environmental pressure caused by economic activities (Wiedmann, 2009a). It is based on input-output economics. The IO tables of an economy consist of monetary transaction matrices describing transactions between economic sectors. With environmental extension, environmental indicators (such as GHG emissions) are added to the matrices (Leontief, 1970).

Consumption-based carbon footprints are assessed by allocating all the life cycle emissions caused by the production of goods and services to the consumer of those goods and services. The life cycle emissions are derived from EE IO analysis. The main benefit of the method is that it avoids the truncation error related to process LCA methods. EE IO analysis is a comprehensive top-down method. However, the comprehensiveness comes with the downside of roughness. The model assumes the homogeneity of prices, outputs and emissions at the sector level (Wiedmann, 2009a). Hybrid LCA methods combine EE IO analysis and process LCA, aiming at strengthening the method (Suh et al., 2004).

2.3. The carbon footprint models of the study

In the study, we used the EE IO model of the Finnish economy, called ENVIMAT (Seppälä et al., 2009, 2011). The functional unit is the carbon footprint of an individual consumer during one year (CO_2-eq t/year). The ENVIMAT model includes 50 COICOP consumption categories. The model is from the year 2005 and we used inflation coefficients (consumer price index) to update the model to 2006 and 2012. The used inflation coefficients are specific for each of the 50 consumption categories. However, no changes in GHG intensities caused by technological development are included in the models, aside from the changes in the direct emissions caused by electricity and heat energy production. The model also captures the impact of vehicle fuel efficiency on the GHG emissions caused by private vehicles since it directly affects the fuel purchases of households. However, the model does not capture the same vehicle fuel efficiency impact on GHG emissions caused by freight and commercial traffic, which could potentially decrease the GHG intensity of goods and services.

We used a tiered hybrid LCA method, meaning that we integrated process LCA data into the IO model in order to assess the combustion phase emissions caused by electricity, heat and motor fuel consumption. We took into account the varying energy prices by both city and housing type in the carbon footprint models. We used city-specific coefficients for district heating and the national average for electricity. We used constant emissions (kg/MWh) for the upper tier emissions (production of fuels etc.) of heat and electricity production. One of the economic sectors of the ENVIMAT model is waste management, and the model includes GHG emissions from landfilling. Thus, the scope of the study is from cradle-to-grave. The model includes also non-fossil GHG emissions, such as methane emissions caused by landfilling and animal husbandry.

We did not use the monetary value of rentals and imputed rentals to assess any emissions. Instead, we compensated for the maintenance charges and rents in the household budget surveys by using statistics from Statistics Finland on the financial statements from housing companies (Statistics Finland, 2015). The statistics provide the average expenses of housing companies per square meter of living space. Apartment buildings and terrace houses are separated, as well as buildings of different ages. Thus, we could use the living space and year of construction to allocate the expenses,

and related emissions, of housing companies for the households. In addition, we assessed the emissions caused by housing construction by using an estimate based on living space: 0.7 CO_2-eq t/m^2 (Säynäjoki et al., 2017). Our previous study (Ottelin et al., 2015) provides more details about the method.

In the study, we divided carbon footprints into eight consumption categories: housing energy, housing, private vehicles, public transport, holiday travel, food, services and tangibles. "Housing energy" includes heat and electricity and "housing" includes other housing-related consumption, such as housing maintenance and repair, household waste and water management, construction and secondary homes. "Private vehicles" includes cars, motorcycles and other motor vehicles and their use, maintenance and repair. "Holiday travel" includes buying tickets for trips abroad, domestic passenger transport by air and sea, package holidays and miscellaneous consumption abroad. However, hotels and restaurants fall under "services".

2.4. The regression analysis of the study

We studied the impact of the urban zone on carbon footprint and emissions caused by housing energy and motor fuel consumption with regression analysis. We separately tested income and expenditure as explanatory variables. In both cases we included household size and dummy variables related to age (over 64-year-olds; under 25-year-olds) as control variables. We lean on previous literature on the drivers of carbon footprints (Lenzen et al., 2004, 2006; Weber and Matthews, 2008; Shammin et al., 2010). We compared the regression models of 2006 and 2012 in order to analyse the development of carbon footprints in different urban zones. We only had data on these two years, and not on the years between, since the household budget survey is only conducted once in every five years. Also, the data is not longitudinal but cross-sectional. For these reasons we could not apply panel data regression models.

3. Analysis of the economic and demographic development of the HMA

Table 1 displays the sample sizes (in households) and share of population living in each type of zone in 2006 and 2012. The share of the population living in public transport and intensive public transport zones increased, while the share of the population living in car zone and the pedestrian zones of subcentres decreased. This suggests that the urban structure of the HMA generally densified rather than sprawled during 2006–2012, which is in line with the mitigation strategy of the HMA. The total population of the HMA increased from 1.00 to 1.08 million inhabitants during the same time. However, the area increased too, due to changes in municipal boundaries, and thus the total population density of the HMA increased only a pinch, from 1340 to 1400 inhabitants/km^2.

Table 1
The sample sizes and share of the population in the studied urban zones.

Urban zone	Sample size		Share of the population	
	2006	2012	2006	2012
The central pedestrian zone	46	54	8%	8%
The fringe of the central pedestrian zone	68	68	11%	11%
Intensive public transport zone	127	137	20%	23%
Public transport zone	155	184	28%	29%
Car zone	87	103	18%	16%
The pedestrian zones of subcentres	76	76	13%	11%
Total	568	629	100%	100%

Table 2 provides descriptive statistics of the studied urban zones in 2012. In addition, the table presents the change from 2006 to 2012 as a percentage. The changes are only suggestive, however, since many of them are smaller than the standard error of the number in question. Changes larger than the standard error are in bold. Throughout the study, we consistently convert the euros in 2006 into 2012 currency.

As Table 2 reveals, inflation-corrected income declined on average 6% in the HMA between 2006 and 2012. However, the decline was not evenly distributed between the urban zones. The central pedestrian zone and car zone, which are the two zones with the highest income level, had the steepest decline of income. In intensive public transport zone the average income actually increased. Furthermore, the median income increased in all zones (8% on average). Table A1 in the appendix reveals that the decline of income in the central pedestrian zone and car zone was mostly due to a drop in income from capital. This was mainly caused by the economic crisis in 2008. Earned income decreased in these zones as well and in the HMA in general. In addition to the economic crisis, migration, increasing amount of pensioners, and residential segregation may have affected the changes in income levels (Vilkama et al., 2014). The economic crisis increased the unemployment rate as well, though the difference between 2006 and 2012 is small (Statistics Finland, 2017).

The changes in household size tell us that intensive public transport zone especially increased in popularity among families with children, whereas car zone had the strongest decline in average household size. As Table 1 revealed, the population declined in car zone. Table 2 shows that the population aged too, suggesting that elderly residents without children increased their share. This may have been due to the policies restricting new construction in car zone. Small households were concentrated in the pedestrian zones of subcentres. The central pedestrian zone and its fringe kept their popularity among small households as well. The age of the population declined most in the central pedestrian zone and its fringe. Living space decreased in the central pedestrian zone and public transport zone. Because of the recession, the period was a quiet construction period – the average construction year increased by one year (from 1972 to 1973) during the six years according to the Household Budget Surveys.

In addition to changes in the urban zones, there were also other relevant changes between 2006 and 2012 following climate change mitigation policies at city, national and international levels. The average emissions caused by the combustion phase of electricity production declined from 280 CO_2 kg/MWh in 2006 to 223 CO_2 kg/MWh in 2012 in Finland (Kurnitski and Keto, 2010; Motiva, 2017). In the case of district heating, the average emissions declined nationally from 219 CO_2 kg/MWh to 209 CO_2 kg/MWh. In the HMA, however, the respective average emissions of district heating in Helsinki, Espoo and Vantaa were 179, 222 and 185 CO_2 kg/MWh in 2005 and 188, 273 and 255 CO_2 kg/MWh in 2012 (Finnish Energy, 2017). This was due to the increased use of coal and decreased use of natural gas in combined heat and power (CHP) production in the HMA. The fuel composition of CHP is largely market driven. The emissions of CHP production are allocated for electricity and heat using the so-called benefit allocation method in all cases in the study.

The fuel efficiency of vehicles increased as well. The average emissions of new passenger cars decreased from 179 CO_2 g/km in 2006 to 140 CO_2 g/km in 2012 (Trafi, 2017a). Nonetheless, the average emissions of the fleet decreased much less, depending on how many new cars were bought and how many and what sort of cars were scrapped. The total CO_2 emissions caused by passenger cars declined quite modestly between 2006 and 2012 in Finland

Table 2
Descriptive statistics characterizing the studied zones in 2012 and change (%) from 2006 to 2012.

Urban zone	Average income €/year per capita		Median income €/year per capita		Average household size persons		Average living space m2 per capita		Average age of citizens years		Average construction year of residential buildings
The central pedestrian zone	30,700	**−22%**	25,500	10%	1.7	−6%	38	**−12%**	46	**−6%**	1944
The fringe of the central pedestrian zone	22,500	−3%	21,000	1%	1.6	−2%	33	3%	43	**−7%**	1959
Intensive public transport zone	23,000	**10%**	20,600	9%	1.9	**12%**	36	−4%	48	−1%	1975
Public transport zone	22,200	1%	19,000	1%	2.2	4%	36	**−11%**	48	0%	1979
Car zone	25,800	**−20%**	24,000	15%	2.1	**−12%**	47	6%	49	**11%**	1983
The pedestrian zones of subcentres	23,800	6%	21,800	9%	1.6	**−11%**	40	6%	49	−1%	1978
The HMA average	23,900	**−6%**	21,000	8%	1.9	−1%	38	**−4%**	47	0%	1973

For averages, changes larger than the standard error are in bold.

(Trafi, 2017b). The average kilometres driven per capita remained similar as well (Finnish Transport Agency, 2012).

4. Results and discussion

4.1. The average carbon footprint of the HMA

Fig. 2 illustrates how the average carbon footprint per capita developed between 2006 and 2012 in the HMA. The total carbon footprint decreased from 10.9 CO_2-eq t in 2006 to 10.2 CO_2-eq t in 2012, equalling a 7% decrease in six years. Average income per capita dropped from €25,300 to €23,900 (−6%) during the same time, but average expenditure increased from €20,200 to €20,500 (1%) in 2012 currency. The changes in expenditure are described in detail in Table A2 in the appendix, which also presents the GHG intensities of consumption categories in 2012 currency.

The GHG emissions caused by housing energy consumption decreased the most (240 CO_2-eq kg; −15%), which can be explained by the decline in the GHG intensity of electricity production and the improved energy efficiency of buildings. The emissions of district heating increased however. In addition, the average living space shrank 1.5 m^2 per capita (−4%). The emissions caused by driving and maintaining private vehicles decreased second most, by 210 CO_2-eq kg (−12%). Reduced motor fuel consumption explains 180 CO_2-eq kg of this. At the same time, emissions caused by public transportation and holiday travel increased, 120 CO_2-eq kg (12%) in total, which suggests that some of the private driving shifted to public transportation.

In addition to the emissions caused by driving and housing energy consumption, the emissions caused by tangibles, services, food and housing in general decreased as well. Technology does not explain the decrease of emissions in these other consumption categories since the model could not capture that. In fact, the decline was probably steeper in reality, because both the greening of electricity production and increased energy efficiency should influence the production of goods and services as well. What may explain the decrease of the emissions of “the rest of consumption” in the study is the division of expenditure. The increase of total expenditure is due to increased expenditure on rentals and imputed rentals, the purchase of cars, the repair and maintenance of private vehicles, buying tickets for trips abroad and buying audio-visual equipment (Table A2, appendix). Of these, only the latter two caused a significant increase of emissions. It appears that particularly the increased living costs in the HMA decreased other forms of consumption and related emissions. The higher living costs did not increase the GHG emissions caused by housing either. A plausible explanation for the increased living costs is the lack of new construction during 2006–2012 and a simultaneous increase of the population. Thus, it was not only the steered mitigation policies that reduced carbon footprints.

There is an interesting detail in the expenditure on holiday travel as well. The popularity of package holidays decreased clearly but at the same time the expenditure on tickets for trips abroad increased (Table A2, appendix). Since the expenditure on accommodation did not increase that much, one could assume that the use of alternative and cheaper accommodation – such as that provided by Airbnb, couch surfing, and staying with friends and relatives – increased. However, the GHG intensity of tickets for trips abroad (air tickets) is much higher (1.5 CO_2-eq kg/€) than the GHG intensity of package holidays (0.8 CO_2-eq kg/€) – so it is not clear whether the impact of this social change in international travel is good or bad for the environment, despite the increasing sharing of houserooms between households.

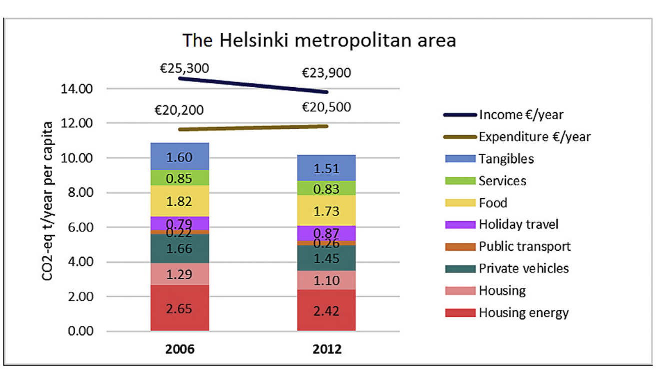

Fig. 2. The average carbon footprint in the Helsinki Metropolitan Area in 2006 and 2012.

4.2. Carbon footprints in urban zones

Fig. 3 demonstrates how the average carbon footprint, income and expenditure of the residents of different urban zones changed in the HMA during 2006–2012. The total carbon footprint in 2012 was highest in the central pedestrian zone (13.9 CO_2-eq t per capita; −2% change from 2006), and second highest in car zone (11.3 CO_2-eq t; −6%). The residents of public transport zone had the lowest carbon footprint: 9.0 CO_2-eq t (−14%). In the other zones, carbon footprints were quite similar in size: 9.7 CO_2-eq t (−1%) on the fringe of the central pedestrian zone; 9.9 CO_2-eq t (+3%) in intensive public transport zone; and 10.0 CO_2-eq t (−4%) in the pedestrian zones of subcentres.

Public transport zone had the most remarkable decline in carbon footprint (−14%). The residents of the zone seem to have benefited from both: policies targeting housing energy

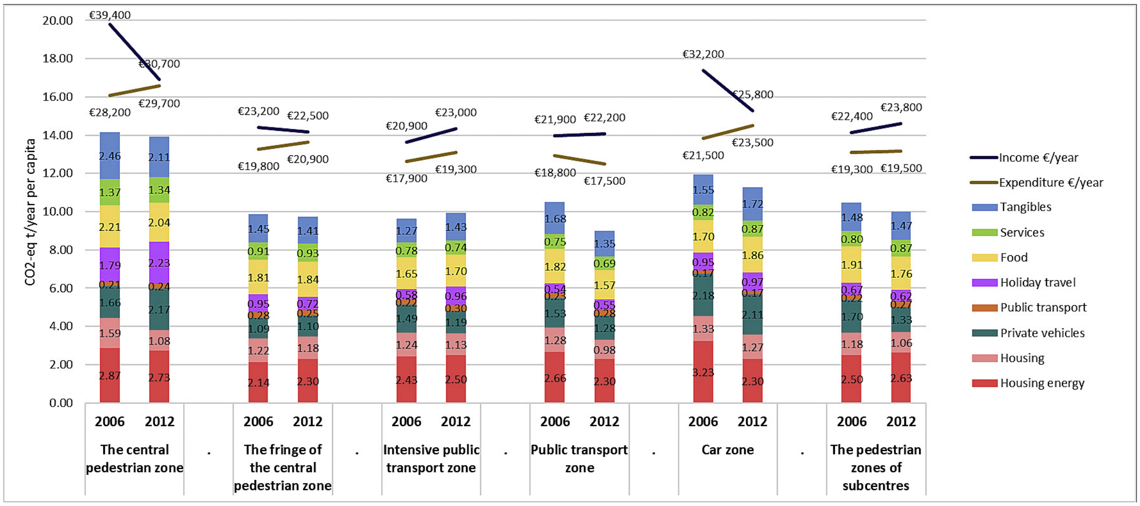

Fig. 3. The average carbon footprints in the studied urban zones in the Helsinki Metropolitan Area in 2006 and 2012.

consumption and policies targeting private vehicles. Here it is important to notice that both national and local governments have strong mitigation policies targeting these emissions. The emissions caused by housing energy consumption decreased most strongly in car zone and public transport zone, which are the two outermost zones of the HMA. As a previous study has demonstrated, low-rise areas with detached houses have benefited more from recent energy efficiency improvements (such as heat pumps and improved insulation) than high-rise areas (Ottelin et al., 2015). This has not only affected new buildings. Heat pumps, new insulation and new heating systems have been installed into older buildings as well, especially in detached houses. For example, the consumption of heating oil decreased 58% during 2006–2012 in the HMA (Table A2, appendix), suggesting that old oil heating systems were replaced extensively. Oil used to be a common heating method for detached houses.

The significant decrease of driving-related emissions cannot be explained by technological development alone. The national statistics reveal that the impact of technological development on the average fleet has been relatively slow. The fleet in the HMA is similar to the rest of Finland (Trafi, 2017c; Statistics Finland, 2012). Thus, changes in travel behaviour probably played a stronger role. This is also in line with the climate change mitigation strategy of the HMA. Increased urban density, increased availability of public transportation, investment in cycling routes, changed attitudes towards driving or all of these may have contributed to the reduction of emissions caused by car use.

The GHG emissions caused by private vehicles declined most in intensive public transport zone, public transport zone and the pedestrian zones of subcentres. In public transport zone and the pedestrian zones of subcentres the decrease seems to be realized in the decrease of the total carbon footprint. However, intensive public transport zone provides a warning example of what can also happen – the increase of holiday travel and public transport exceeded the decrease gained from reduced driving. The emissions caused by holiday travel seem to increase with the level of urbanization within the city. Car zone is an exception: there the emissions increase again. Previously Brand and Preston (2010), Holz-Rau et al. (2014), Ottelin et al. (2014) and Reichert et al. (2016) have presented similar findings on the relationship between the level of urbanity and long-distance travel. Our results on the GHG emissions of holiday travel are well in line with these studies using kilometres travelled to assess the emissions.

There are interesting similarities between the two most affluent zones in the HMA: the central pedestrian zone and car zone. The income drop between 2006 and 2012 was almost entirely due to the steep decline in these zones. In addition, the income level declined mildly at the fringe of the pedestrian zone. What is curious about all three zones is that the decrease of income did not lead to a decrease of expenditure – quite the opposite: average expenditure increased. Thus, the income drop did not reduce the carbon footprints that are essentially driven by expenditure.

4.3. Regression analysis

Income and expenditure have been found to have a similar relationship with carbon footprint (Ala-Mantila et al., 2014). Nonetheless, as Figs. 2 and 3 illustrate, the expenditure did not follow income very well during 2006–2012 in the HMA. Thus, we decided to run regression analysis with income and expenditure separately as explanatory variables. Table 3 presents the income models and Table 4 the expenditure models. In addition to the models below, we tested also models with other control variables. These models can be found in the appendix (Tables A3 and A4).

The regression models for total carbon footprint in 2006 and 2012 reveal an interesting pattern. When households with a similar income level are compared, there were no statistically significant differences between the car zone and the other zones in 2006 (Table 3, Model 1a). In 2012, however, all the other zones between the central pedestrian zone and car zone had 12–16% (coeff. –17 to –13) lower carbon footprints than car zone. There was no statistically significant difference between the central pedestrian zone and car zone. The result suggests that there may be an optimal urban density range, whereas an extremely dense or extremely sprawled urban structure leads to increasing emissions. Previously, Jones and Kammen (2014) have demonstrated similar results for the US.

On the other hand, the expenditure model, which describes the GHG intensity of consumption, shows that only the fringe of the central pedestrian zone had a lower carbon footprint than car zone, both in 2006 and 2012 (Table 4, Model 2a). Otherwise, there were no statistically significant differences between the zones. Taken together, the results emphasize the similarities between the central pedestrian zone and car zone that Fig. 3 illustrates as well. The

Table 3
Regression analyses comparing the studied urban zones in the HMA in 2006 and 2012 with income as an explanatory variable.

Regression model	Model 1a				Model 1b				Model 1c			
Dependent variable	ln (CF[a])				ln (CF housing energy)				ln (CF motor fuel)			
	2006		2012		2006		2012		2006		2012	
Prob > F = 0.000 in all models	$R^2 = 0.60$		$R^2 = 0.49$		$R^2 = 0.48$		$R^2 = 0.36$		$R^2 = 0.25$		$R^2 = 0.34$	
	Coef.	P>|t|	Coef.	P>|t|	Coef.	P>|t|	Coef.	P>|t|	Coef.	P>|t|	Coef.	P>|t|
ln (disposable income per capita)	**0.61**	0.000	**0.56**	0.000	**0.44**	0.000	**0.35**	0.000	**0.35**	0.000	**0.23**	0.002
Household size: 1 person (ref.)												
2 persons	−0.03	0.507	−0.09	0.051	**−0.25**	0.000	**−0.32**	0.000	**−0.45**	0.002	**−0.51**	0.000
3 persons	**−0.14**	0.005	**−0.24**	0.000	**−0.42**	0.000	**−0.52**	0.000	**−0.62**	0.000	**−0.73**	0.000
>3 persons	**−0.10**	0.047	**−0.40**	0.000	**−0.44**	0.000	**−0.59**	0.000	**−0.69**	0.000	**−0.96**	0.000
Seniors (>64 y)	−0.08	0.053	−0.07	0.076	**0.23**	0.000	**0.22**	0.000	−0.13	0.250	−0.11	0.180
Young (<25 y)	−0.01	0.882	0.07	0.484	**−0.32**	0.028	−0.03	0.713	0.03	0.880	−0.37	0.106
Urban zone: Car zone (ref.)												
The central pedestrian zone	0.02	0.740	0.03	0.777	**−0.16**	0.045	0.03	0.760	**−0.38**	0.037	**−0.28**	0.031
The fringe of the central …	−0.10	0.060	**−0.17**	0.037	**−0.25**	0.001	−0.04	0.627	−0.20	0.160	**−0.28**	0.045
Intensive public transport zone	−0.07	0.113	**−0.13**	0.006	−0.11	0.109	**0.15**	0.029	−0.19	0.098	**−0.31**	0.001
Public transport zone	0.00	0.940	**−0.14**	0.003	−0.06	0.435	0.07	0.306	−0.19	0.085	**−0.37**	0.000
The pedestrian zones of subcentres	−0.02	0.686	**−0.14**	0.008	−0.13	0.099	0.07	0.418	−0.15	0.231	**−0.29**	0.013
Constant	**3.25**	0.000	**3.82**	0.000	**3.72**	0.000	**4.37**	0.000	**4.60**	0.000	**5.83**	0.000

[a] CF = carbon footprint per capita; regression coefficients with $p < 0.05$ are in bold.

Table 4
Regression analyses comparing the studied urban zones in the HMA in 2006 and 2012 with expenditure as an explanatory variable.

Regression model	Model 2a				Model 2b				Model 2c			
Dependent variable	ln (CF[a])				ln (CF housing energy)				ln (CF motor fuel)			
	2006		2012		2006		2012		2006		2012	
Prob > F = 0.000 in all models	$R^2 = 0.88$		$R^2 = 0.84$		$R^2 = 0.44$		$R^2 = 0.35$		$R^2 = 0.25$		$R^2 = 0.34$	
	Coef.	P>|t|	Coef.	P>|t|	Coef.	P>|t|	Coef.	P>|t|	Coef.	P>|t|	Coef.	P>|t|
ln (expenditure per capita)	**0.93**	0.000	**0.89**	0.000	**0.45**	0.000	**0.34**	0.000	**0.45**	0.000	**0.29**	0.000
Household size: 1 person (ref.)												
2 persons	0.03	0.131	−0.03	0.332	**−0.22**	0.000	**−0.31**	0.000	**−0.41**	0.002	**−0.46**	0.000
3 persons	0.00	0.869	−0.04	0.217	**−0.44**	0.000	**−0.48**	0.000	**−0.59**	0.002	**−0.64**	0.000
>3 persons	−0.01	0.658	−0.06	0.110	**−0.47**	0.000	**−0.51**	0.000	**−0.65**	0.000	**−0.83**	0.000
Seniors (>64 y)	**0.07**	0.003	**0.09**	0.000	**0.28**	0.000	**0.30**	0.000	−0.11	0.323	−0.08	0.361
Young (<25 y)	−0.07	0.054	0.05	0.286	**−0.46**	0.001	−0.11	0.098	−0.05	0.814	**−0.42**	0.042
Urban zone: Car zone (ref.)												
The central pedestrian zone	−0.06	0.097	−0.06	0.386	−0.17	0.062	0.01	0.897	**−0.45**	0.018	**−0.28**	0.022
The fringe of the central …	**−0.09**	0.003	**−0.08**	0.029	**−0.28**	0.001	−0.04	0.644	−0.20	0.128	−0.23	0.074
Intensive public transport zone	−0.02	0.551	0.05	0.112	−0.12	0.105	**0.20**	0.005	−0.19	0.093	**−0.27**	0.004
Public transport zone	0.00	0.897	0.04	0.237	−0.09	0.280	0.12	0.106	−0.20	0.061	**−0.33**	0.000
The pedestrian zones of subcentres	−0.03	0.406	0.01	0.817	−0.17	0.055	0.10	0.241	−0.16	0.195	**−0.24**	0.037
Constant	0.17	0.418	0.36	0.188	**3.76**	0.000	**4.52**	0.000	**3.64**	0.001	**5.20**	0.000

[a] CF = carbon footprint per capita; regression coefficients with $p < 0.05$ are in bold.

declined income did not affect expenditure or the carbon footprint in these zones, which led to the relative increase of carbon footprints in these zones compared to residents with similar income who were living in the other zones. The raw data reveals that the decrease of income was mainly due to the decline of income from capital, not earned income (Table A1 in the appendix), which may explain the low impact on expenditure. Nonetheless, the result suggests that it may be difficult for affluent households to adjust their expenditure in the case of an unplanned decline in income.

It is difficult to say exactly why the fringe of the central pedestrian zone performed better than any other zone. One explanation could be the high living costs (except compared to the central pedestrian zone), which seem to decrease the average living space per capita significantly. The fringe of the central pedestrian zone had the smallest living space of all zones, 33 m^2 per capita, while car zone had the highest, 47 m^2 per capita, in 2012 (Table 1). Notwithstanding, the emissions caused by housing energy consumption were actually not statistically significantly different between car zone and the fringe of the central pedestrian zone in 2012 because of the high influence of mitigation policies targeting housing energy in car zone (Table 3, Model 1b; Table 4, Model 2b).

The income model for housing energy reveals that the negative regression coefficients for the emissions caused by housing energy consumption in 2006 have turned generally positive, or near zero, in 2012 in the other urban zones compared to the car zone (Table 3, Model 1b). The expenditure model demonstrates the same pattern (Table 4, Model 2b). This means that the other zones used to have lower emissions from housing energy consumption than car zone

in 2006 but this was no longer the case in 2012. Intensive public transport zone actually had clearly higher emissions than car zone in 2012. As mentioned above, low-rise areas have benefited more than high-rise areas from the increased energy efficiency of housing.

The analysis of motor fuels, however, produces very predictable results. The emissions from fuels are much higher in car zone than any other zone (Table 3, Model 1c; Table 4, Model 2c). Between 2006 and 2012, the differences in fuel consumption spread even wider between the car zone and the other zones, except for the central pedestrian zone. This can be seen in the decreased negative coefficients of the other zones, and their increased statistical significance in both the income and the expenditure model. Thus, the emissions caused by motor fuel consumption partly explain the relative increase of carbon footprints in the car zone and the central pedestrian zone compared to the other zones.

The control variables also reveal some interesting changes between 2006 and 2012. If we look at young people (under 25-year-olds) in the expenditure model, their motor fuel consumption was at the same level as other households in 2006 but in 2012 it was 35% (coeff. −0.42) lower than others (Table 4, Model 2c). At the same time, their emissions caused by housing energy consumption were 37% (coeff. −0.46) lower than that of others in 2006 but not statistically significantly lower in 2012 (Table 4, Model 2b). The raw data reveals that while the living space per capita generally decreased in the HMA, young people increased their average living space from 24 m^2 to 34 m^2 per capita (still lower than the HMA average of 38 m^2).

Economies of scale due to intra-household sharing have a strong mitigating impact on carbon footprints, as has been found previously (Wier et al., 2001; Ala-Mantila et al., 2016). According to the expenditure model, the impact of household size remained quite similar between 2006 and 2012 (Table 4, Models 2a–c). The income model, however, suggests that the negative impact of household size on carbon footprint strengthened (Table 3, Model 1a). This is at least partly explained by the pattern that income increased but expenditure decreased in large families (>3 persons). Families may be more prone to saving money during a recession, and this could decrease their relative carbon footprint compared to other households with similar income.

4.4. The limitations of the study

The research was designed to overcome some previous problems in consumption-based carbon footprint assessments: the lumping of different urban areas and the crudeness of urban structure measures. The focus on one metropolitan area decreases the error caused by the geographical homogeneity assumption of prices. However, the other general limitations of EE IO analysis, including aggregation error and assumptions of the linearity of prices, remain. In addition, the narrow geographical scope of the study has the downside of decreasing the generalizability of the results. Furthermore, the economic crisis in 2008 makes the time frame of the study quite special. This provides interesting insights but it would be exciting to repeat the study at a time of economic growth to see if the results and conclusions would be different.

As mentioned earlier, the carbon footprint models only capture the technological development related to direct emissions caused by energy production. The impact of technological development on the production of goods and services is not included, which probably overestimates the carbon footprints in 2012 slightly. Likewise, changes in the relationship between imports and exports may impact GHG intensities significantly (Wiedmann, 2009b), but this could not be taken into account in the study.

The emissions caused by the construction of buildings and infrastructure is one of the stumbling blocks of current carbon footprint assessments in the built environment. In the study, we estimated them by using a simple estimate based on living space but the differences between low-rise and high-rise areas, for example, could not be taken into account. Our previous study (Ottelin et al., 2015) elaborates the issue.

4.5. Policy implications

The results of the study highlight the complexity of issues that affect carbon footprints in the built environment. It is important to understand that climate change mitigation policies are interconnected. Changes in the policies regarding energy efficiency and renewable energy change the impact of urban density policies on GHG emissions. Which urban zone is most sustainable in 2050 depends on what happens to the GHG emissions of energy production, vehicle technologies, the level of car ownership, construction materials, integrated renewable energy production in buildings, the amount of holiday travel etc. The strength of the consumption-based carbon footprint assessment used in this study is that it reveals the rebound effects of consumption (Ottelin, 2016; Ottelin et al., 2017). If driving-related emissions are targeted with policies such as motor fuel taxes and encouraging technological leaps, the potential impact of urban density policies decrease. This is because the GHG intensity of driving and owning a car (CO_2-eq kg/€) comes closer to (or even falls below) the GHG intensity of marginal expenditure. Here, marginal expenditure means alternative consumption − if consumers do not drive, or do not own cars, they have the saved amount of money to spend on something else that causes emissions. While driving is expensive (due to fuel taxes and expensive clean vehicles), the alternative consumption may have even worse GHG implications than driving. However, if the emissions caused by driving are not targeted by carbon pricing policies, leading to cheap motor fuels and cars with high fuel consumption, urban density policies do have a strong mitigation impact, since rebound effect is minor. Essentially, it is a question of how we wish to direct GHG emissions.

In the study, the two outermost zones of the HMA, car zone and public transport zone, seem to have benefited most from the policy measures targeting housing energy. The residents of the car zone had higher emissions from housing energy than the residents of the other zones in 2006 but this was no longer the case in 2012. The result demonstrates that technological development can have a very strong impact on GHG emissions, and the impact may depend on urban structure. Thus, instead of strict compact city policies, it could be more effective to target different urban zones with different policy measures. For example, new construction in car zone could be bound to new investments in renewable energy, energy efficiency, and electric and other low-carbon vehicles. This would allow more freedom for people to live according to their preferences but in a sustainable manner.

The results of the study reveal that mitigation policies related to travel behaviour, such as increased public transport availability, have been the most effective in public transport zones and the pedestrian zones of subcentres. Education, information and attitudinal change probably played an important role as well. Toyama city in Japan provides a similar example, where a strong policy of promoting public transport increased the use of public transport, especially within groups that used public transport before the

policy intervention, such as elderly women (Takami and Hatoyama, 2008; Runzo-Inada, 2014). Thus, policies promoting public transport may be most effective when targeted to multi-modal travellers rather than habitual drivers.

The findings highlight that we need stronger measures to reduce GHG emissions in the central locations of the city as well. In these areas, GHG emissions are spread quite evenly over many consumption categories and driving-related emissions only play a minor role. Perhaps these areas could benefit from policies targeting the time use of the residents. The time-use perspective provides an interesting view on the GHG intensity of consumption (Jalas and Juntunen, 2015). Currently, urban density is well exploited by commercial actors but cities could also utilize density to provide uncommercial services and public spaces that would provide less GHG-intensive time-use activities. Perhaps in an attractive and liveable city people would feel less need to consume long-distance holiday travel too, which is one of the most GHG-intensive consumption categories.

What is evident in the study, however, is the huge task of reducing the GHG emissions to a sustainable level in any area. The new target of the Paris Agreement to keep further warming to 1.5 °C below pre-industrial levels (UNFCCC, 2015) and the EU's target to cut emissions by 80% by 2050 (European Commission, 2011) require strong actions. Even if the local combustion-phase emissions of energy production were zero and the emissions of driving negligible, the targets would not be met. To achieve them, we need international policies to tackle the emissions caused by air travel and the embodied emissions of imports. Likewise, we need to target the emissions caused by food consumption and food waste (Millward-Hopkins et al., 2017). It is easy to agree with the emerging recognition that we will need negative emissions technologies (Minx et al., 2017) — such as carbon capture and storage — and regenerative solutions in the built environment (Cole, 2012) in addition to energy efficiency solutions in order to mitigate climate change to a sustainable level. Carbon pricing policies could inspire and speed up the technological development.

5. Conclusions

The purpose of the study was to examine how climate change mitigation policies and other events affected the consumption-based carbon footprints of the residents of the Helsinki Metropolitan Area (HMA) between 2006 and 2012. The cities of HMA launched an ambitious climate change mitigation strategy in 2007. In addition, we analysed how carbon footprints changed within six urban zones of the HMA during the same time in order to examine in more detail how urban structure affects carbon footprints.

The average carbon footprint of the residents in the HMA decreased by 7% (720 CO_2-eq kg), although the average expenditure rose by 1% (€260). This is encouraging since expenditure alone cannot explain the decline. The climate change mitigation strategy of the HMA (YTV, 2007), as well as national and international policies, especially targeted the emissions caused by housing energy and transportation. The results of the study reveal that some important progress was made in these areas. Emissions caused by housing energy consumption were reduced, especially in the car zone and the public transport zone, which are the two outermost zones of the HMA. These areas benefited from the increased energy efficiency of buildings, the reduced use of heating oil and instalments of heat pumps. Driving-related emissions decreased the most in public transport zones and the pedestrian zones of subcentres. In these zones, there was a shift from car use to public transport. Furthermore, policies promoting cycling and walking may have decreased driving.

In addition to steered mitigation actions, other factors also contributed to the decline of carbon footprints. Particularly the increased living costs of the HMA seem to have reduced consumption of other commodities. To achieve the ambitious targets of 40% emissions reduction, let alone carbon neutrality, stronger policy actions are needed. Carbon pricing policies would offer a convenient upper-level solution. Also, it would be important to start to think beyond “low carbon”. Carbon-negative technologies and regenerative solutions in the built environment are under way and should be enhanced.

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Appendix

Table A1
Changes in different income categories in each zone between 2006 and 2012 (€/year per capita).

Urban zone	Earned income	Entrepreneur income	Income from capital	Received income transfers
The central pedestrian zone	−1,960	−2,790	−10,340	990
The fringe of the central pedestrian zone	−3,400	240	1,510	−700
Intensive public transport zone	2,090	−110	1,400	−1,070
Public transport zone	1,440	−770	330	−1,050
Car zone	−3,260	−960	−8,660	2,630
The pedestrian zones of subcentres	−2,080	−210	70	3,150
The HMA average	−760	−660	−1,730	220

Table A2
Expenditure in 2006 and 2012 (both in 2012 currency) and GHG intensities of consumption categories in 2012, applied from Seppälä et al. (2009).

		Expenditure *€/year per capita in 2012 currency*		**Change** *2006-2012 €*	**GHG intensities** *CO2-eq kg/€ in 2012 currency*
COICOP		**2006**	**2012**		
A011a	Food of vegetable origin	1,162	1,113	-49	0.6
A011b	Food of animal origin	1,020	994	-27	0.9
A012	Non-alcoholic beverages	204	198	-5	0.5
A021	Alcoholic beverages and tobacco	571	437	-135	0.2
A031	Clothing	759	571	-188	0.4
A032	Footwear	105	89	-16	0.4
A041	Actual rentals for housing	1,470	1,681	211	
A042	Imputed rentals for housing	3,597	4,147	550	
A043	Maintenance and repair of the dwelling	3	12	9	0.6
A044	Miscellaneous services relating to the dwelling	62	53	-10	0.5
A0451	Electricity	355	343	-12	2.1*
A0453	Liquid fuels	72	30	-42	2.5*
A0454	Solid fuels	6	6	0	1.4*
A0455	Heat energy (district heating and cooling)	110	92	-18	2.8*
A051	Furniture and furnishings, carpets, other floor coverings	437	342	-95	0.3
A052	Household textiles	105	74	-31	0.4
A053	Household appliances	134	140	6	0.4
A054	Glassware, tableware and household utensils	78	92	14	0.4
A055	Tools and equipment for house and garden	76	96	20	0.5
A056	Goods and services for routine household maintenance	156	153	-3	0.3
A061	Medical products, appliances and equipment	240	323	84	0.5
A062	Outpatient services	350	256	-95	0.1
A063	Hospital services	48	36	-12	0.2
A0711	Purchase of motor cars	805	1,082	277	
A0712	Purchase of motor cycles	18	70	53	1.4
A0713	Purchase of bicycles	23	24	1	0.3

A072	Operation of personal transport equipment	838	1,143	304	1.0*
	Motor fuels (subcategory)	575	479	-95	
A0730	Tickets for trips abroad	124	256	132	1.5
A0731	Passenger transport by railway	65	88	23	0.5
A0732	Passenger transport by road	292	336	44	0.6
A0733	Domestic passenger transport by air and sea	22	22	0	1.1
A0735	Other purchased transport services	3	31	28	0.3
A0736	Benefit in kind vehicles	219	175	-45	
A08	Communication	422	500	79	0.2
A091	Audio-visual and photographic equipment etc.	203	347	144	0.8
A092	Other major durables for recreation and culture	253	79	-175	0.7
A093	Other recreational items and equipment, gardens, pets	319	331	12	0.6
A094	Recreational and cultural services	693	625	-68	0.2
A095	Newspapers, books and stationery	437	280	-157	0.3
A096	Package holidays	367	238	-129	0.8
A100	Education	74	51	-23	0.2
A111	Catering services	943	923	-20	0.3
A112	Accommodation services	155	178	23	0.4
A121	Personal care	444	474	31	0.3
A123	Personal effects n.e.c.	211	247	36	0.3
A124	Social protection	171	120	-50	0.2
A125	Insurance	389	375	-14	0.2
A126	Financial services n.e.c.	4	2	-2	0.3
A127	Other services n.e.c.	35	58	22	0.2
P312Y	Travel expenses abroad	573	519	-54	0.5
	Consumption credit interests, misc. taxes, fines etc.	651	602	-49	
		19,873	20,455		

*Average from the hybrid-LCA model of the study. These intensities are not used in the study as such, the model is more sophisticated (see Ottelin et al. 2015 for details)

Changes larger than €100 are marked with blue (decrease) or red (increase) font

Table A3
Regression models with city (Model A1) and children's age (Model A2) as control variables.

Regression model	Model A1		Model A2	
Dependent variable	ln (carbon footprint)			
Year	2012			
Prob > F = 0,000 in all models	$R^2 = 0.49$		$R^2 = 0.49$	
	Coef.	P>|t|	Coef.	P>|t|
ln (disposable income per capita)	**0.56**	0.000	**0.57**	0.000
Household size: 1 person (ref.)				
2 persons	−0.09	0.053	**−0.10**	0.044
3 persons	**−0.24**	0.000	**−0.28**	0.000
>3 persons	**−0.40**	0.000	**−0.46**	0.000
Seniors (>64 y)	−0.07	0.069	−0.07	0.104
Young (<25 y)	0.07	0.529	0.08	0.436
Urban zone: Car zone (ref.)				
The central pedestrian zone	−0.01	0.950	0.03	0.771
The fringe of the central pedestrian zone	**−0.20**	0.027	**−0.17**	0.038
Intensive public transport zone	**−0.17**	0.002	**−0.13**	0.006
Public transport zone	**−0.15**	0.001	**−0.14**	0.003
The pedestrian zones of subcentres	**−0.16**	0.004	**−0.14**	0.009
City: Helsinki (ref.)				
Espoo	0.00	0.971		
Vantaa	−0.09	0.085		
Small children			0.03	0.702
School children			0.07	0.264
Adult children			0.03	0.675
Constant	**3.87**	0.000	**3.70**	0.000

Regression coefficients with $p < 0.05$ are in bold.

Table A4
Regression models with socioeconomic class (Model A3) and household type (Model A4) as control variables.

Regression model	Model A3		Model A4	
Dependent variable	ln (carbon footprint)			
Year	2012			
Prob > F = 0,000 in all models	$R^2 = 0.52$		$R^2 = 0.46$	
	Coef.	P>|t|	Coef.	P>|t|
ln (disposable income per capita)	**0.49**	0.000	**0.58**	0.000
Household size: 1 person (ref.)				
2 persons	**−0.13**	0.003		
3 persons	**−0.32**	0.000		
>3 persons	**−0.51**	0.000		
Urban zone: Car zone (ref.)				
The central pedestrian zone	0.01	0.896	0.05	0.665
The fringe of the central pedestrian zone	**−0.19**	0.016	−0.15	0.087
Intensive public transport zone	**−0.15**	0.002	**−0.11**	0.029
Public transport zone	**−0.13**	0.008	**−0.13**	0.005
The pedestrian zones of subcentres	**−0.15**	0.004	−0.11	0.058
Sosioeconomic class: Entrepreneur (ref.)				
White collar high	−0.08	0.250		
White collar low	**−0.15**	0.014		
Blue collar	**−0.15**	0.037		
Student	**−0.29**	0.040		
Pensioner	**−0.32**	0.000		
Unemployed	**−0.49**	0.016		
Other work status	−0.14	0.227		
Household type: Adult singles (ref.)				
Adult couples			−0.09	0.186
Young			0.05	0.651
Seniors			**−0.12**	0.052
Young families and single parents			**−0.24**	0.001
Other families with children			**−0.32**	0.000
Constant	**4.68**	0.000	**3.58**	0.000

Regression coefficients with $p < 0.05$ are in bold.

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